Control of Heat and Humidity in German Mines

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ABSTRACT

In order to increase the economic efficiency of West European hard coal, great efforts are being made at present in the coal-producing countries to lower production costs. This aim is to be achieved in Germany, among other things, by a drastic increase in the saleable output per working face up to an average of 10,000 t/d in these cases where very long longwall faces (400 m ± 50 m) are possible. With the substantially greater heat input into the air stream which this involves, there is the danger that climatic limits will be exceeded even at longwall faces with lower than average rock temperatures. Working in high temperatures and/or humidities can lead to risky lack of concentration of the miners or to heat collapse and extremely dangerous heat stroke. In order to minimize the costs for mine climate control well-proven planning software and climitization technology is necessary for underground workings. With the DMT climate simulation programs, both the dry and the extremely significant humid heat transfer can be calculated and the optimum air cooling system for a mine can be designed with due regard to technical and economic aspects.

KEYWORDS

Task of Air-Conditioning in Mines, Reasons for Climate Planning, Different Air-Conditioning Systems, Location of Central Refrigeration Plants, Dependency of Air-Coolers of Working Conditions, and Pressure Reducing Facilities.

INTRODUCTION

The average depth of German coal mines today is in the 1,000 m range, with the greatest depth being around 1,600 m. Here the rock temperature exceeds 60°C which is just the same as in 3,500 m deep South African gold mines.

The average run-of-mine coal per working face at present is approximately 5,000 t/d, peak values of more than 20,000 t/d are obtained. On average, the longwall faces are 310 m long, the maximum length being around 450 m. The average effective work seam thickness is 1.90 m. In long and high performance faces the nominal electrical power of the installed machinery can be up to 4.5 MW including the conveyor belts in the panels.

The widely branched mines with roadway systems of sometimes more than 100 km total length and the control of dust, methane inflows as well as rock and machine heat place the highest demands on the quality of the ventilation. Moreover, also on the air conditioning, which is necessary today in practically all winning operations and mechanical roadway headings in German hard coal mining. At present German hard coal mining has installed refrigeration facilities with a cooling capacity totalling more than 240 MW.

DMT's experience in the fields of ventilation and air conditioning is based on:

- planning work for the ventilation and air conditioning of complex mines including auxiliarly ventilated roadway headings and tunnel structures,
- acceptance inspections underground and consultancy for mine and tunnel operators,
- development projects on various problematic fields in ventilation and air conditioning.

TASK OF THE AIR CONDITIONING

The major task of an air conditioning system at working faces, in road headings or in entire mines is to guarantee tolerable climatic conditions. For the evaluation of the climatic burden for miners in Germany, first the dry-bulb temperature is used and then the so-called effective temperature. The latter is a quantity determined by calculation or taken from a chart, and it is made up of the physiologically effective influences of temperature, relative humidity and air is lower than the "normal" dry temperature. It conforms to this with static air and 100 % relative humidity.

Based on the Air conditioning in Mines Regulation (Kimabergverordnung, 19__) of the German coal mining industry there is no restriction for on-site working hours at dry-bulb temperatures of up to 28°C or effective temperatures of up to 25°C when working underground. At higher dry-bulb or effective temperatures working hours are shortened from the normal level of 8 hours per shift to 6 or 5 hours per shift. Above an effective temperature of 30°C work underground is allowed under exceptional circumstances only and it is completely forbidden at temperatures above 32°C. A survey of the "Klimabergverordnung" is given in Table 1. Furthermore, a number of European countries have taken over at least parts of this regulation for tunnelling operations.

Table 1. Summary of the German Mine Regulations for Climatic Conditions in non-salt mines

Temperature t_d	Temperature t_{eff}	Duration of shift h	Duration of Working time h	Additional work break min
≤ 28°C	≤ 25°C	8	No restriction	-
> 28°C	> 25°C	8	6	-
	> 29°C	8	5	10
		working only under exception		
	> 30°C	8	5	20
	> 32°C	No working		

If ventilation of mines is not by itself sufficient to comply with the climatic limits regarding costly working time cuts and complete work prohibition, additional facilities for mechanical air cooling will be used.

OBJECTIVES OF CLIMATE PLANNING

Before new mines are developed, panels or working faces are developed in places where climatic difficulties are to expected, one should investigate among other things whether and at what expense tolerable climate conditions can be created. A precondition for this is a reliable climate plan. With such a plan it is possible to determine which measures and, if necessary, which refrigeration capacities are required, as well as which working conditions can be created for the work force.

With great success climate plans have been drawn up for German salt, ore and especially for hard coal mining with their exceptionally high rock temperatures, and also for mining as well as tunnelling in other countries for over 30 years with the exclusive use of climate prediction programs developed by DMT, thanks to the high planning reliability they offer. It is possible to calculate the dry heat exchange as well as the highly significant humid heat exchange with them. The software is adapted to keep pace with mining and mechanical developments in underground operations by our experienced mining engineers as the need arises.

In the climate planning of entire mines, individual working faces or roadway heading, the prime question is whether it is possible to prevent the climatic limits laid down reliably from being exceeded. And this without having to enforce a reduction in the planned heading speed or production rate. Basically the aim in roadway heading in German mining and in European tunnelling is to keep the climatic values at the working face below a dry-bulb temperature of 28°C and the effective temperature away from the face below 29°C, even with the above-mentioned high rock temperatures and with intensive machine operation, e.g., part-face or full-face cutters. If other sites are set up in the area away from the face, these are also cooled to a dry-bulb temperature of below 28°C.

In the longwall faces of German hard coal mines the lower air conditioning target of 28°C with comparatively high output is achieved only for a maximum rock temperature of around 35°C. With higher rock temperatures, this air conditioning target can be maintained only at unreasonable expenses. It can not at all be achieved with very high rock temperatures because of technical reasons. In these cases the air conditioning systems are designed in such a way that the effective temperature in the whole workings does not exceed 29°C. The climate plan can be adjusted to any other climate limit as maybe laid down in the different national regulations.

AIR CONDITIONING SYSTEMS

If it is not possible to comply with specified climatic limits by means of ventilation measures alone, air conditioning systems must be provided. About 60 % of the total cooling capacity of German hard coal mining is installed in air cooling systems with a centralised arrangement and the rest is found in decentralised systems.

With the support of the DMT climate prediction program it is possible to design an optimum air cooling system for a mine or parts thereof with due regard to technical and economic aspects, at the same time taking account of local features.

Decentralised Cooling

Decentralised air cooling systems are generally used only if the required total cooling capacity of the mine is relatively low or if merely wide-strewn, single separate working faces or headings have to be cooled. Usually this holds for comparatively small refrigeration machines with a relatively low average cooling capacity of 280 kW, installed singly or in pairs underground near the working face that is to be cooled. A decentralised air cooling system normally consists of an aircooling machine (direct evaporator). In general the aircooling machine is divided into two parts to increase its mobility and it is then suspended on an overhead monorail or stands on runners. The first part of the machine contains the liquefier and the compressor. The second part comprises the direct evaporator. Both components are very compact (dimensions in each case are about 1 m x 1 m x 3 m) and they are connected by short, reinforced, flexible refrigerant lines. The condenser heat is discharged into the service water network if the machine does not have its own cooling water system.

Air Conditioning Systems with Centralised Refrigeration

In the case of large total refrigeration capacities, preference should be given to an air cooling system with centralised refrigeration for economic and technical reasons. Figure 1 shows the main components of an air cooling system with centralised refrigeration.Up to mine depths of about 1,800 m water circuits in shafts are closed and can be used as communicating pipes. For economical reasons the water circuits in greater depths have to be opened (in this case it could be an advantage to produce ice at surface like in South African gold mines) or a more economic three chamber pipe feeder has to be interposed.

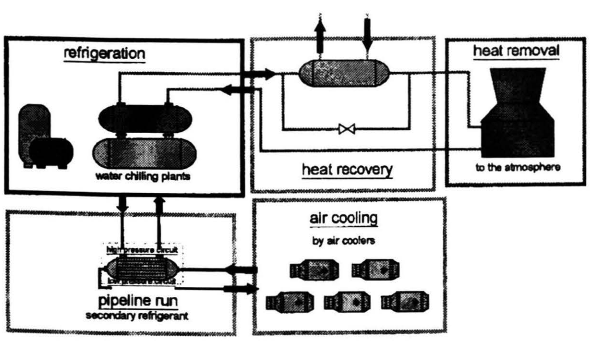
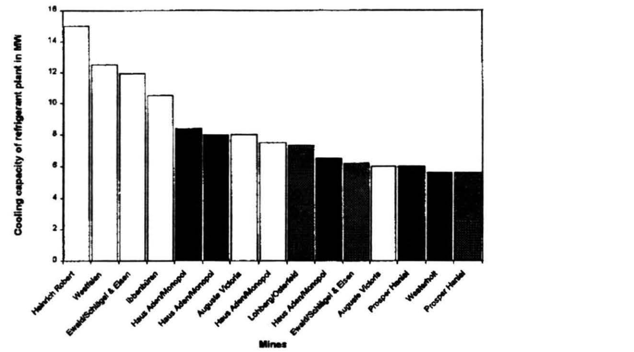


Figure 1. Air cooling system with centralised refrigeration.

The central refrigeration plant can be installed at the surface, underground or combined at surface and underground. The best location results from the climate planning and cannot be defined generally. In German hard coal mines the biggest refrigeration plants of air cooling systems (capacities above 10 MW) are located at the surface, refrigeration plants in medium ranges (between 5 and 10 MW) are not only located at surface but also underground and even combined at surface and underground. All smaller refrigeration plants are installed underground. In Figure 2 the biggest refrigeration plants of German hard coal mining are shown.



Location of central refrigeration plant:
(white) at surface (black) underground (grey) combined

Figure 2. The biggest air conditioning systems with centralised refrigeration plants in German hard coal mining.

A centralised cooling installation consists mainly of a number of chilled water machines connected in series with individual capacities of between 1 and 4 MW. Mines covering a very large area often have several air cooling systems with one centralised cooling installation at their disposal. The greatest cooler capacity that is installed in a German mine with several air conditioning systems amounts to around 31 MW.

The central refrigeration system can be located above ground or underground or combined above ground and underground. The selection of the location is geared to the specific conditions of each mine. If there is enough open space above ground then the central cooling system can be installed there (see Figure 3). In this case flameproofing of the electric components within the refrigeration system can be dispensed with. Another advantage is a minimum expense for monitoring and maintenance, heat availibility at a central point (if heat recovery is demanded), applicability of different refrigerants and possibility of precooling of air at the intake shaft in wintertime. But at least the chilled water flow line in the shaft must be properly insulated. In addition, in the area around the shaft landing one of the pressure-reduction facilities described later must be provided.

If the conditions above ground are too confined, the centralised cooling system can also be installed underground near a shaft landing if possible (see Figure 4). To a certain extent, the dimensions of refrigeration machines can be chosen freely and can therefore be adapted quite easily to the spacial conditions underground. For example one can make use of compact or very narrow, drawn-out units. In almost all coal mines, flameproofing has to be considered for refrigeration systems installed underground. As a rule the heat emitted from the refrigeration machines is conveyed to the surface via a cooling water shaft circuit. Since large quantities of water have to be conveyed in the cooling water circuit than in the chilled water circuit, accordingly the shaft circuit for cooling water must be of larger dimensions than that for chilled water. But the cooling water pipe normally does not need insulation. In the case of underground refrigeration, pressure-reducing devices can be dispensed with if high-pressure condensers are installed.

Generally, the location of the central refrigeration plant combined at the surface and underground (see Figure 5) has the advantage of relatively low chilled water volume flow with large spread of temperatures between advance and return in the shaft (small pipe diameters in the shaft are possible) and of precooling of intake air at the surface.

As a rule, the heat emitted from the refrigeration system is removed into the atmosphere by means of a cooling water circuit and cooling tower or wet recooler.

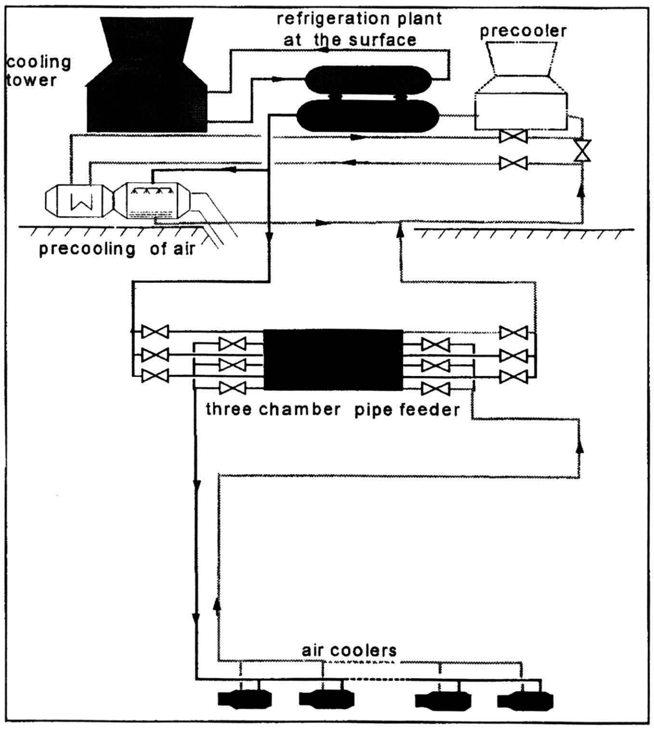


Figure 3. Air cooling system with central refrigeration plant at the surface.

Within the climate plan the most practical locations as well as the design and number of the air coolers have to be selected. Then the chilled water volume flows per cooler must be determined, taking into account of the calculated, air-side cooler inlet conditions at the cooling location, the air volume flow, the chilled water flow temperature and the refrigeration losses in the chilled water piping system, so that the cooling capacities required at the cooler locations can be transferred. DMT has a thorough knowledge of the performance characteristics of a large variety of cooler types suitable for mining as a function of the respective operating

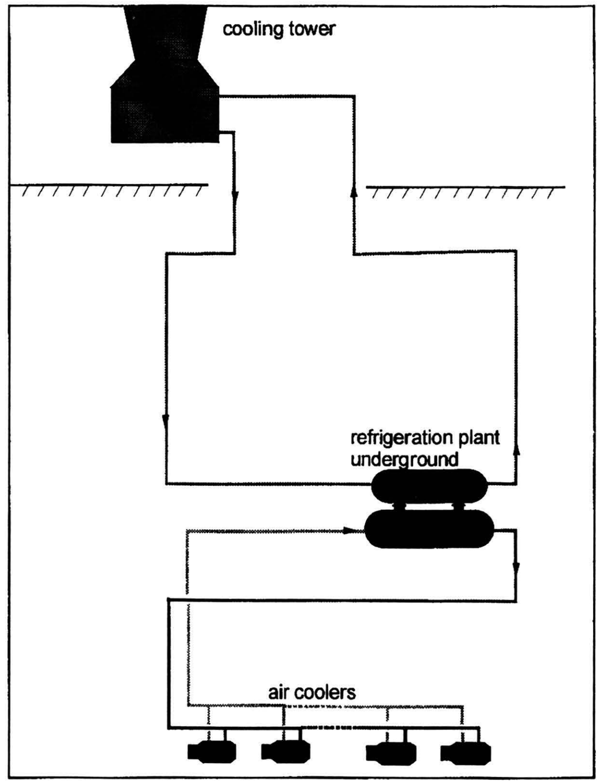


Figure 4. Air cooling system with central refrigeration plant underground.

conditions, because all these cooler systems were tested on DMT's own climate test rig. The thermal characteristics determined on the test rig are recorded in corresponding files for each cooler type and are needed for the software part with which the performance of the cooler can be determined dependent on the operating conditions.

Figure 6 shows that it is critical to have chilled water volume flows that pass through the air coolers set correctly. Under otherwise constant operating conditions the efficiency of the air cooler increases when the water volume flow rises. Should the water volume flow be set too low, it might not be possible to meet the specified air conditioning target, to which a certain minimum cooling capacity has to be assigned.

Figure 7 shows the relationship between the cooler capacity and the air volume flow which flows through the cooler for a specific cooler type suitable for use in mines in otherwise constant conditions. It can be seen that with an increase in the airflow, the cooler capacity also increases. Figure 8 illustrates the dependency of the cooler capacity on the chilled water inlet temperature of a specific cooler type under otherwise constant conditions. The curve makes clear how important it is for the water to reach the air cooler as cold as possible to achieve the greatest cooler capacity.

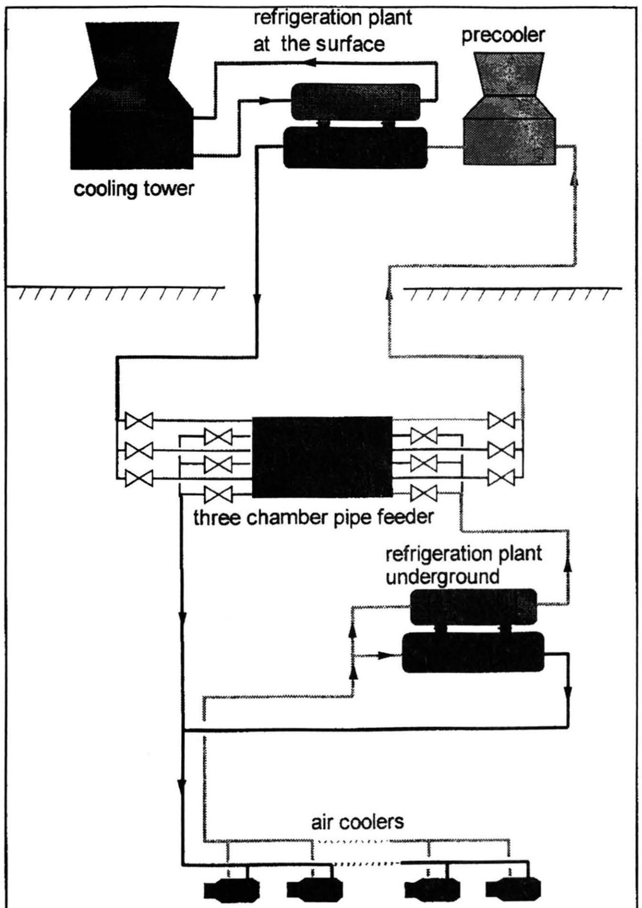
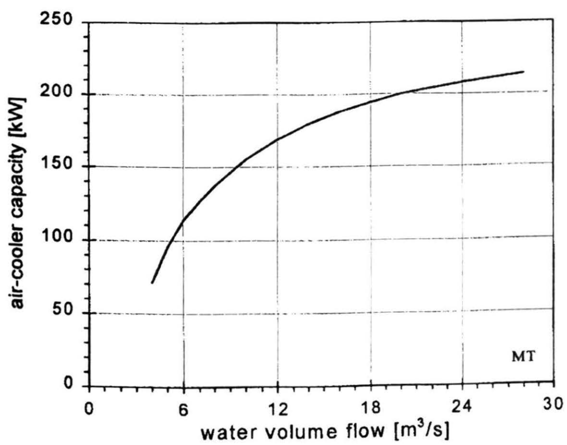
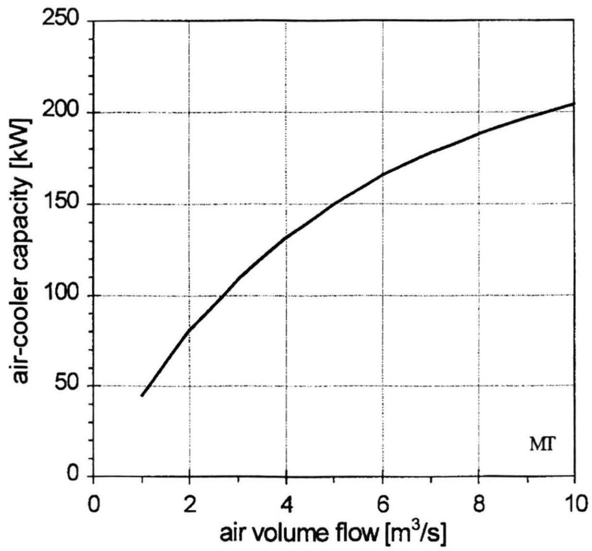


Figure 5. Air cooling system with central refrigeration plant combined at the surface and underground.



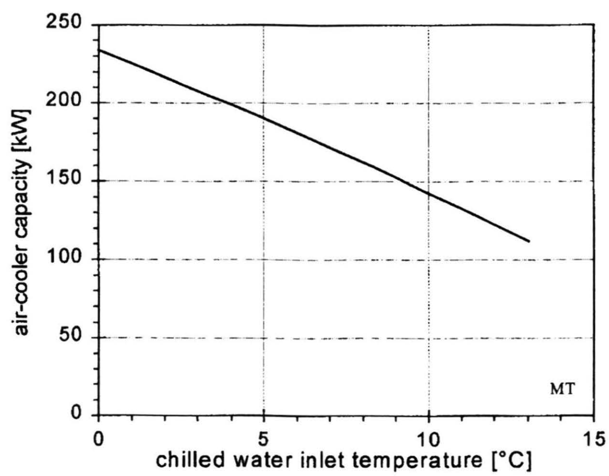
Conditions:
t_{db} = 28 °C; t_{wb} = 23 °C; $t_{E,H2O}$ = 7 °C; V_{air} = 6.3 m³/s

Figure 6. Cooler capacity in relation to chilled water volume flow.



Conditions:
t_{db} = 28 °C; t_{wb} = 23 °C; $t_{E,H2O}$ = 7 °C; V_{H2O} = 12.4 m³/h

Figure 7. cooler capacity as a function of air volume flow.



Conditions:
t_{db} = 28 °C; t_{wb} = 23 °C; V_{H2O} = 12.4 m³/h; V_{air} = 6.3 m³/s

Figure 8. Cooler capacity as a function of chilled water inlet.

The dimensioning of the chilled water network is geared to the necessary volume flows. The flow lines in the chilled water network are totally insulated in order to feed the water to the air coolers as cold as possible for reasons just mentioned. Then there are stable pipes with water vapour-proof insulation with heat transfer coefficients of less than 2 W/(m²K) which have proven suitable in rough underground operation. This involves two steel pipes pushed over one another (see Figure 9). The cavity between the two pipes is air-tight and filled with fire-proof polyurethane foam. Since the collar on the flanged connection of the pipes was provided with insulating materials, there is no longer any metallic, i.e. no highly heat-conducting connection between the inside pipe containing chilled water and the flanges or metallic outer pipe.

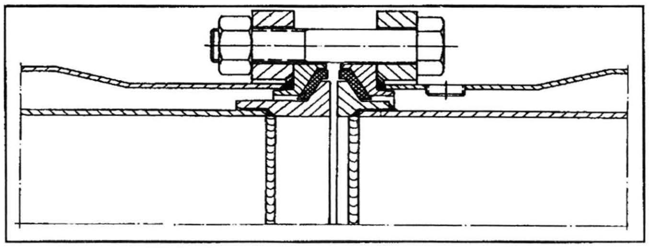


Figure 9. Insulated chilled water pipes suitable for mines.

Pressure reducing facilities are used with large static pressure differences in the chilled water network, which occur, for example, when chilled water lines are laid in shafts. In general, such facilities are high-pressure/low-pressure heat exchangers, three-chamber pipe feeders or a Pelton turbine. For reasons of cost and safety, the pressure allowed in the underground chilled water system should not exceed 40×10^5 Pa (= 40 bar). The three-chamber pipe feeder is the most effective pressure reducing facility in closed chilled water circuits because the chilled water is conducted from the high pressure to the low pressure side of the air cooling system - practically without an increase in chilled water temperature. Figure 10 shows the principle of a three-chamber pipe feeder.

The total capacity needed for a central cooling installation is made up of the sum of the maximum cooler capacities needed in future and the cold losses in the piping system. In many cases only a fraction of the total cooler capacity needed later at its maximum is needed at the start of any air conditioning measures. The cooling installation including pumps should therefore be of modular design so that the full investment costs for the air conditioning system are not incurred right at the beginning.

As already mentioned above, the chilled water should be as cold as possible when fed into the air coolers. For this reason chilled water machines equipped with tube evaporators should also be able to achieve chilled water flow temperatures of 3 °C in continuous operation without anti-freeze having to be added. This requires a well functioning power regulation system with corresponding monitoring equipment. The chilled water machines installed in the other industries produce flow temperatures around 6 °C at most, which are less suitable for mining. When the more expensive plate-type evaporators are used, chilled water flow temperatures of 1 °C are also achieved reliably and without additives.

SUMMARY

With the help of internally developed software that has been tried out over many years it is possible to calculate in ad-

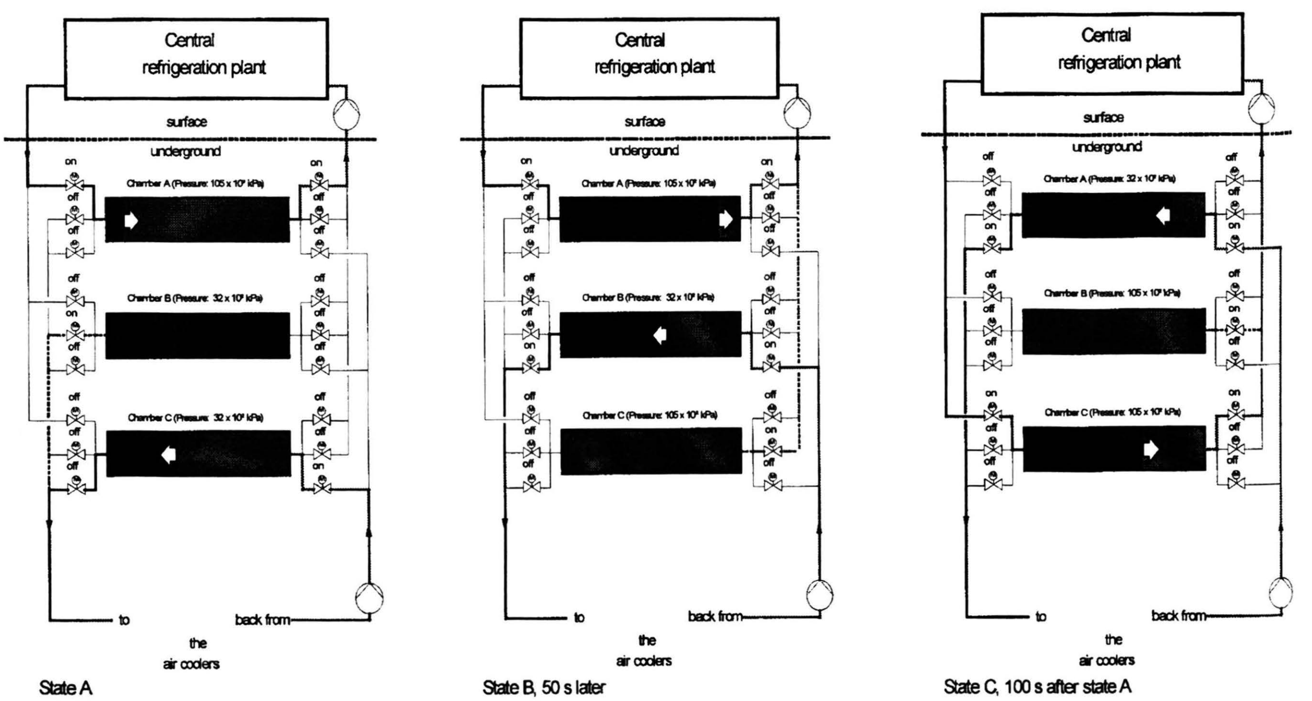


Figure 10. Principle of a three-chamber pipe feeder.

vance the expected climatic conditions for mines or parts of mines like panels or auxiliarly ventilated headings, and to design the required ventilation and air conditioning equipment. Major climate-affecting factors are the rock temperature, the machinery used for working or heading, the face advance or the heading rate and the air flow.

If it is not possible to keep to the specified climatic limits by taking ventilation-related measures, then air conditioning facilities must be planned, with due regard to the technical and economical aspects. Decentralised air-cooling systems are only then used generally if the required total refrigeration capacity in the mine is relatively low or, if only widely strewn single working faces have to be cooled. In the case of large total refrigeration capacities, preference should be given to an air cooling system with centralised refrigeration for economic and technical reasons.

REFERENCE

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